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HOW REAL ARE VIRTUAL ENVIRONMENTS?: A VALIDATION OF LOCALIZATION, MANIPULATION AND DESIGN PERFORMANCE

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ABSTRACT

Immersive simulation techniques such as Virtual Environments (VE) can revolutionize human factors engineering and training projects provided that they are carefully validated. Is human performance in the virtual world the same as in the real world? When visual aspects perceived on a virtual ship differ from those perceived on a real ship, human factors engineering studies may yield non-optimal designs. When interactions with virtual worlds are not natural, training may not transfer to the real world.

I will discuss three studies that compared human task performance in real and virtual (HMD) environments. First, we carried out spatial perception experiments and measured localization performance: how well can people indicate the center point between two objects in identical virtual and real environments. Second, manipulation performance was measured: how well can people grab, turn and position objects in virtual environments and what adaptation effects occur when returning to the real world. Third, we compared the assessment of ergonomic aspects of identical virtual and real ship bridges.

Discrepancies found between the results for the real and the virtual bridge are discussed in terms of challenges with respect to the quality of head-mounted display optics and tracking devices and, most importantly, with respect to natural interfaces needed for manipulation (virtual hand control) and for moving around in virtual worlds (intuitive navigation methods).

SPATIAL PERCEPTION IN VE

This study focused on the quantification of spatial perception in virtual environments as a quality measure for realism and functionality. The accuracy of spatial positioning tasks was psychophysically quantified for subjects in an immersive visually simulated environment: a 5m x 5m Engine Control Center of a Dutch M-frigate. Performance in the real environment was compared with the performance of identical tasks in its virtual counterpart.

One type of task (bisection) was to position a hand-held pointer at an imaginary bisection point between two markers in 3D space (separated 2m to 6 m). Another type of task (positioning) was to position the pointer at a certain distance from the wall. Virtual space was simulated using a Polhemus' Fastrak head-tracking device, Evans and Sutherland's ESIG 2000 high performance image generator (64 ms delay time) and an Eyegen 3 head-mounted display (colour, stereo, a 40 degree field of view).

The typical distance between indicated and actual bisection points was approximately 20 cm in the real versus 30 cm in the virtual environment (a 50% increase in errors). Positioning tasks show an even higher increase in errors (approximately 90%). These data show that our 3D spatial bisection and positioning tasks are sensitive to the impairment of spatial perception in (high performance) virtual environments due to a simultaneous decrease of spatial resolution, field of view and/or delayed visual feedback. In a separate experiment it was shown that field of view alone was not responsible for the degraded performance in VE. Further, experiments in a virtual environment with only isolated markers in an empty environment show that subjects integrate environmental structure spatially for optimal positioning performance. The detailed modelling of environmental structure appears to be an important property of virtual (and probably of real) environments.

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

MANIPULATION PERFORMANCE IN VE

The application of Virtual Environment techiniques in training projects often requires a high-level natural interaction with the environment. Virtual hand control is the most natural manual interaction method called direct manipulation. Direct manipulation allows users to grasp, rotate and move virtual objects with a realistic virtual hand that mimics the real hand. Such intuitive manipulation methods potentially enable advanced applications in the field of interactive design, training, medicine, etc. However, they should be carefully evaluated.

We have studied manipulation performance in virtual environments using direct (virtual hand control) manuplation compared with indirect (mouse driven 3D cursors) manipulation. These manipulation methods were tested under monoscopic and stereoscopic viewing conditions. Participants were asked to discriminate, grasp, pitch, roll and position virtual objects. Both speed and accuracy of manipulation tasks were measured.

Virtual hand control proved to be significantly faster (35%) and more accurate (40%) than 3D mouse cursor control. Virtual hand control affected more head movement which was available in both conditions. Head movements induce motion parallax (a powerful visual depth cue). Further, it was shown that the speed and accuracy of manipulations strongly improve under stereoscopic viewing conditions. Stereoscopic viewing also significantly increased the sensitivity to size differences between objects (50% better).

ADAPTATION OF EYE-HAND COORDINATION IN VE

Above we mentioned that performance (speed, accuracy) of direct manipulation (virtual hand control) is much faster and far more accurate than that of indirect manipulation (traditional mouse driven 3D cursor control). However, in current virtual environments the virtual hand may not always be exactly aligned with the real hand due to imperfect optics or due to tracking errors. Such misalignment may cause an adaptation of the users' eye-hand coordination and possibly a decrease in manipulation performance compared to aligned conditions. Therefore, we have studied visuo-motor adaptation as well as performance decrease under misaligned virtual hand conditions using a prism adaptation paradigm.

Participants were immersed in an interactive virtual environment with a deliberately misaligned virtual hand position (a lateral shift of 10 cm). We carried out pointing tests with a non-visible hand in the real world before (pre-test) and after (post-test) immersion in the virtual world. A comparison of pre- and post-tests revealed after-effects of the adaptation of eye-hand coordination in the oppositie direction of the lateral shift (negative after-effects). The magnitiude of the after-effect was 20% of the lateral shift under stereoscopic viewing conditions. Interestingly, decreased manipulation performance (speed/accuracy) during the immersion with misaligned hand compared to aligned hand conditions was not found. The occurrence of negative after-effects in lateral direction indicates lower level parameter adjustment of eye-hand coordination. This is promising for those interested in using virtual hands to acquire visuo-motor skills. Acquired skills in VE are likely to transfer to the real world.

DESIGN TASKS

By order of the Royal Netherlands Navy, TNO developed and evaluated a prototype VE-system which enables the interactive 3D design of operational areas of a ship and which offers a wide range of specific human factors engineering tools. The evaluation of the prototype system focussed on the functionality and validity of the system. We have evaluated the VE-system on the basis of a series of tests carried out by eight subjects on the virtual bridge of the Hr.Ms. Mercuur. For verification purposes, the results of the tests on the virtual bridge were compared with those obtained with identical tasks on the real bridge. First, we tested reachability for examining the perceptual and geometrical quality of the proto-type system. Second, accessibility was tested to quantify the speed and ease of navigation and obstacle avoiding in VE. Third, we tested how well participants could manually grasp and position a bearing-compass given a set of ergonomic constraints.

Results showed serious perceptual deformations of spatial dimensions in the virtual environment for all tests. Misperceptions may be partly explained by imperfect head-mounted display (HMD) optics. For the other part, modeling and tracking problems must have caused the problems. Further, objects in the virtual environment (VE) were not always recognizable and in some cases appear to be (or are) different from the real environment (RE). This caused serious discrepancies between the results of our design task in VE and RE.

We also found that accessibility studies in VE take significantly longer than in RE and that subjects collide with obstacles in VE far more often in VE than in RE. This finding is likely to be due to the relatively narrow field of view of current HMDs and to non-intuitive navigation methods.

These results indicate that virtual environments have to be very carefully modeled and in sufficient detail before they can be used for evaluation tasks such as reachability and accessibility tests. Furthermore, head-mounted displays have to be carefully tuned to the properties of the human visual system using high quality optics. Feedback delays should be reduced. Finally, new, more intuitive methods for navigating in VE may improve a user's sense of orientation in VE and the functionality of accessibility studies.

Knowledge of flaws (as emerging from the current validation studies) enables us to correct VE models and display techniques such that human factors studies can be safely carried out in VE. When thoroughly validated, VE can be a powerful tool for even more advanced human factors engineering studies (reachability, accessibility, interactive design) than the ones that have already been carried out successfully with VE (view, layout). The benefits of VE in terms of participation, risk reduction, cost reduction and design optimization are evident.